Ph. D. Synopsis

1.	Title of Dissertation:	Experimental Studies of Hard Turning Parameters for Case Hardening Steels.
2.	Name of Department:	Mechanical Engineering.
3.	Name of Programme:	Ph.D. (Mechanical Engineering)
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7.	Expected Completion Date:	Three years from date of registration.
8.	Name of Guide:	Dr. B. M. Dabade.
9.	Ph. D Recognition of Guide:	PG / RG / RECOGN / 2001-2002 / 4919-21

Experimental Studies of Hard Turning Parameters for Case Hardening Steels

1. Introduction

Hard turning is effective finish turning of hardened materials with 45HRc+ with tipped or solid cutting inserts, preferably CBN. Hard machining was beyond the application range of conventional carbides. Metal cutting machine with desired stiffness and high spindle speed was the other hurdle for hard machining. Traditionally, all hardened parts such as gears, shafts, bearing races with hardness between HRc 45-68 are ground to obtain the required tight tolerances and surface finish. The productivity of grinding is limited because of limitations on the wheel diameter, the speed of cutting, and the contact arc length. With improved rigidity of the high performance CNC machine tools and cutting tools of cubic boron nitride and ceramics, hard machining is extensively and successfully being used to process complex work pieces in one step, and achieve size tolerances and finishes approaching grinding quality. Hard turned parts do not need always to be ground for finishing specifications. The secret to successful hard turning is high cutting speed. While finish turning a steel shaft at 120 m/min with 0.2 mm depth of cut, the hardness of 60 Rc will drop to Rc hardness in the 30s range. All of the heat generated at this cutting speed is concentrated where the chip is being formed, causing it to anneal ahead of the cutting action, while the parent material remains unaffected. With increase in speed, this annealing effect is even more pronounced, and hardness of the chips drops further. With higher speed, the tool machines more parts before a change, and directs most of the heat away from the part surface into the chips, which disintegrate into disposable size. Representative cutting parameters are as shown in table. [AB Sandvik Coromant (2005)]

Table 1: Representative parameters for hard turning [AB Sandvik Coromant (2005)]

Work piece materials	Cutting speed(m/min)	Feed (mm/min)	DOC(mm)
Carbon and alloy steels(50-60HRc)	90-150	0.050-0.20	0.08-0.50
Die Steels(55-65HRc)	45-100	0.050-0.20	0.08-0.20

1.1 Basic requirements of Hard Turning: A rigid set up is a necessity for hard turning. It may be overhang of tool holder or work piece.

- **Machine tools**: A precision lathe or more so a turning center is used for multi-surface machining of parts in one chucking keeping part features in proper relation to one another. If possible, a chucking CNC lathe may be dedicated to hard turning the parts instead of hard turning on all machines. Any well-maintained 2-axis CNC lathe (not necessarily a new one) with rigid tool holders and chucks may be good enough for hard turning.
- **Cutting tools**: Ceramics and CBN are the most common tool materials for hard turning. Table below provides a comparison of the properties of the two tool materials and that of tungsten carbide for reference.

1.2 Comparison between Hard turning and Grinding

Surface generation

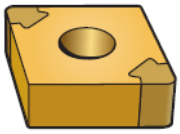
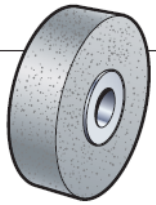
	 Turning	 Grinding
Method	Single point contact	Multi point contact
Profile	Periodic One	Irregular Many
Residual stress	Compressive (mainly)	Compressive (mainly)
Surface profile		

Fig 1: Comparison between Hard Turning & Grinding [AB Sandvik Coromant (2005)]

Decision about the preference of one process over the other is to be subjective and not biased. Hard turning is an alternative process, and in many cases the grinding can be replaced by hard turning. However, in many situations grinding can only be a solution.

- **Surface finish:** Surface topographies of both the processes are different. Rougher but metallurgically undamaged hard turned surface hastens lapping and super-finishing operations. But on a sealing surface the helical lays of hard turning are detrimental, and grinding only provides that smoothness. A well-controlled hard turning will rarely cause

thermal damage on the part surface unless a very blunt tool or incorrect geometry is used. Hard turning is far superior in maintaining surface integrity of turned surface in comparison to grinding that is a poor process so far energy efficiency is concerned.

- **Metal removal efficiency**: Hard turning is advantageous when finishing machined sections with a certain maximum aspect ratio of cut width vs. DOC. Beyond that, hard turning is no longer competitive with a plunge grinding operation in cycle time. If the width is too much, a single point turning may be more efficient in turning the step.
- **Coolant:** Hard turning with ceramics and CBN is generally dry. Necessity of coolant for grinding is a strong negative aspect.
- **Process flexibility:** Turning is inherently more flexible and allows multiple surfaces machining in one chucking. Setup changes are relatively quick, particularly on CNC lathe. Grinding, even a sophisticated one will have some limitations.
- **Tolerances**: Hard turning can achieve tolerances of less than 0.13mm and surface finishes as low as 0.3µm Ra, though the lay is helical. However, grinding can hold a tolerance of 1µm and surface finishes below 0.25µm. A judicious combination of hard turning and grinding may be more productive. An intermediate hard turning may reduce the stock for grinding which may be the final operation, and the cycle time gets reduced. Two clear approaches are emerging. In one, hard turning followed with super-finishing is replacing grinding for the finishing. In second, a creep feed grinding process eliminates bulk material removal processes followed again by super-finishing as final machining operation.

- **Cost Comparison between Hard Turning & Grinding**

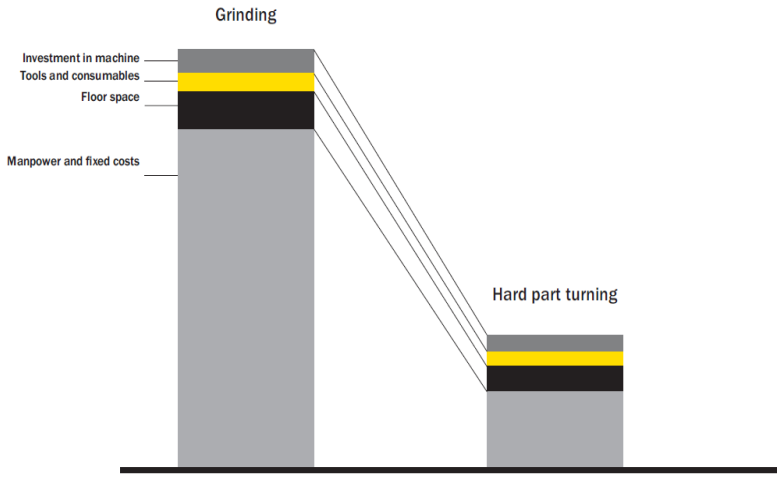


Fig 3: Cost Comparison between Hard Turning & Grinding

2. Literature Review

Jouini et al. (2013) in their investigation on the ability of precision hard turning to increase rolling contact fatigue life reported that Precision hard turning generates homogeneous thicknesses of fine white layer and transition zone. Nano indentation tests have revealed that the white layer is about 50% harder than the bulk material hardness, and the transition zone is about 30% softer than bulk material. RCF life of bearing steel components machined by precision hard turning reached 5.2 (at Ra=0.11 mm) and 0.32 million cycles (at Ra=0.25 mm). Therefore, RCF life increases as the roughness amplitude Ra decreases. In comparison with precision hard turning (RCF life reaches 5.2 million cycles for Ra=0.11 mm), the RCF life of the bearing components finished by grinding process reached 1.2 million cycles (Ra=0.2 mm), whereas in grinding followed by honing process it reached 3.2million cycles (Ra=0.05 mm).

Suresh et al (2012) in their investigation of Some studies on hard turning of AISI 4340 steel using multilayer coated carbide tool reported that The feed rate has highest physical as well statistical influence on the machining force to perform the machining operation (53.38%) followed by depth of cut (36.04%) and cutting speed (6.75%). Machining force initially increases with increase in feed rate and depth of cut and decreases with increase in cutting speed. The reduction in the forces is probably due to temperature increase in the shear plane area, resulted in a reduction in shear strength of the material. The feed rate has highest influence on the specific cutting force to perform the machining operation (70.55%) followed by depth of cut (14.05%) and cutting speed (13.42%). At lower feed rate, shear of material DoEs not fit adequately to the chip formation process. As the material is subjected to lower strain rates, it leads to an increase in the specific cutting force.

Grzesik & Krzysztof (2012) in their investigation of Modification of surface finish produced by hard turning using super finishing and burnishing operations reported that Hard turning and integrated turning-abrasive and turning burnishing technological processes produce a variety of surfaces with different geometrical and service properties. As a result, Super finishing and burnishing operations can improve surface finish and bearing properties of surfaces on hardened parts produced by conventional HT. The roughness reduction expressed by the ratio of Rat/Rab is equal to 1.71 for surfaces turned with Wiper inserts and 16.62 when standard inserts were used. It means that the improvement of the surface roughness through the ball burnishing process is about 40% and 94%, respectively.

El Hakim et al (2011) in their investigation of Wear behavior of some cutting tool materials in hard turning of HSS reported that It could be formed due to abrasive and adhesive wear increase with an increase in the cutting speed owing to the increase of the slip distance and the cutting temperature during machining. EDS analysis reveals that the tool flank surface contains mainly aluminium and oxygen but also titanium and iron from the work piece material, which is in good agreement with the insert run at 100 m/min (Fig.3).

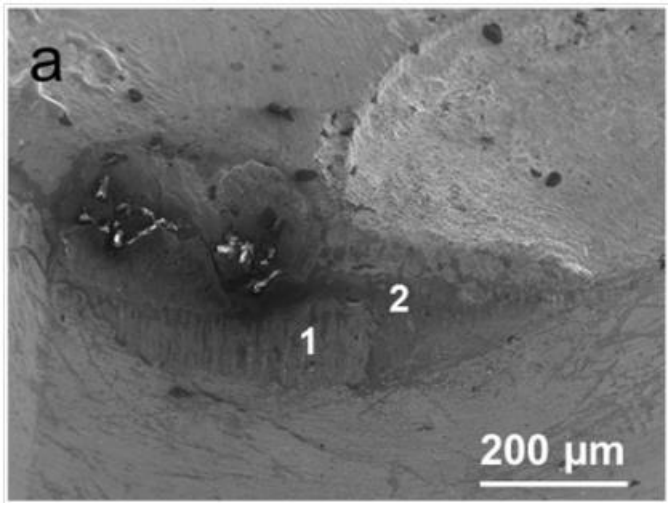


Fig 3: SEM micrograph of CT3 used in the 200m/min test and EDS spectra

Guddat et al (2011) in their investigation of Hard turning of AISI 52100 using PCBN wiper geometry inserts and the resulting surface integrity reported that the influence of the insert on the microstructure varies with the different tool geometries and tool wear (Note that white and dark layers are not found at any settings.) With increasing tool wear the microstructure is affected in greater depth and micro structural changes are more visible. The conventional insert mainly leads to flow lines in the material. These flow lines enlarge and grow into increasing depth (up to 4 µm) with increasing tool wear. When regarding the SEM pictures of the work piece machined with a new and worn wiper insert, the flow lines are much less visible. Micrographs after machining with worn conventional and wiper insert respectively (Figures 4 a and b).

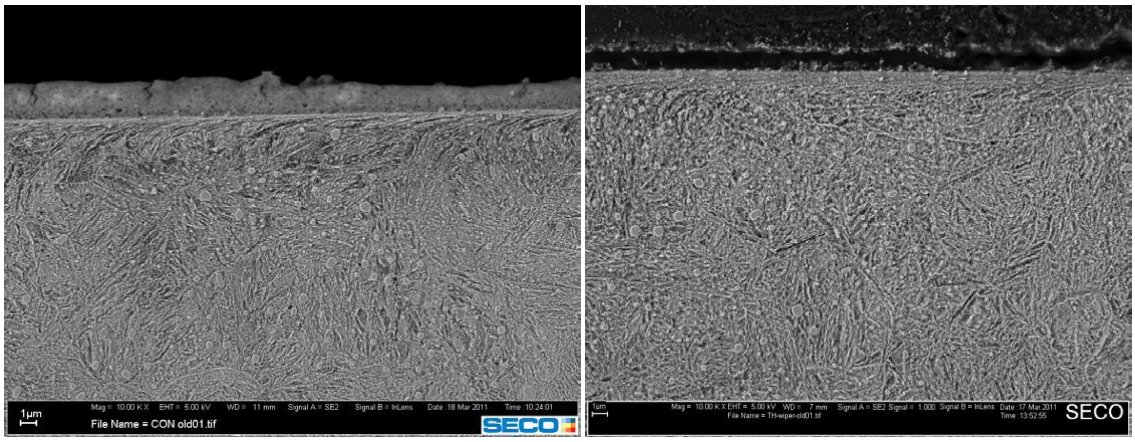


Fig 4: Micrographs after machining with (a) conventional insert; (b) wiper insert

Guddat et al (2011) in their investigation of Hard turning of AISI 52100 using PCBN wiper geometry inserts and the resulting surface integrity reported that Increasing feed has a great effect on surface roughness. This increment of roughness however, is greater using a conventional insert. Increasing the nose radius leads to better surface finish. Here again the wiper insert is more stable to different nose radii (Fig 5a & 5b).

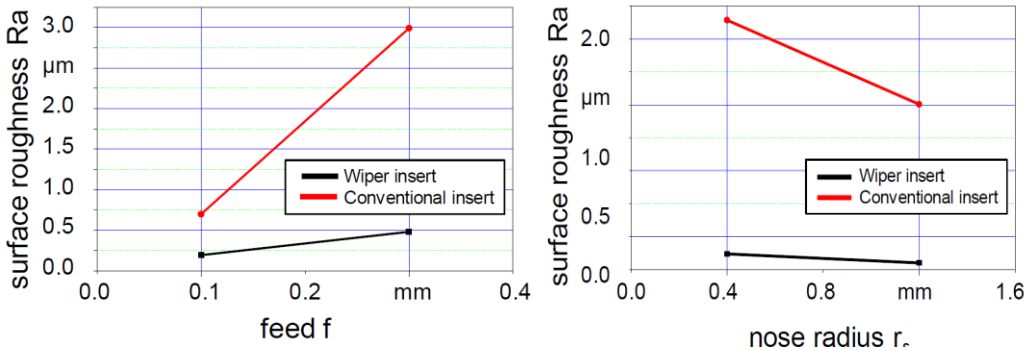


Fig 5: (a) Interaction Plot: feed (f) x inserts type; (b) Interaction Plot: nose radius (rε) x insert type

Further they reported that with increasing tool wear, the surface roughness value resulting from the wiper inserts increases, while it decreases with the conventional insert. Both inserts tend to reach a stable value after a specific cutting time. Regarding Ra (Fig.5) the surface produced using a wiper insert is superior to the surface produced using an insert with conventional geometry continuously.

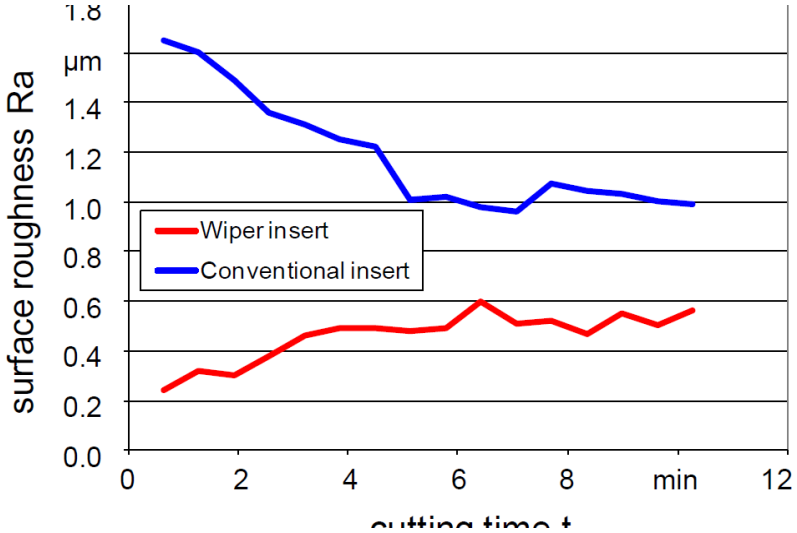


Fig 5: Ra plotted against contact time

Grzesik & Wanat (2006) in their investigation of Surface finish generated in hard turning of quenched alloy steel parts using conventional (Fig. 6a) and wiper ceramic inserts reported that wiper-style inserts specially designed for hard turning with ceramics and CBN provide new levels of productivity. With these multi-radius type inserts (Fig. 6b) the same surface finish can be maintained using double the conventional values of feed rates of 0.05–0.20 mm/rev.

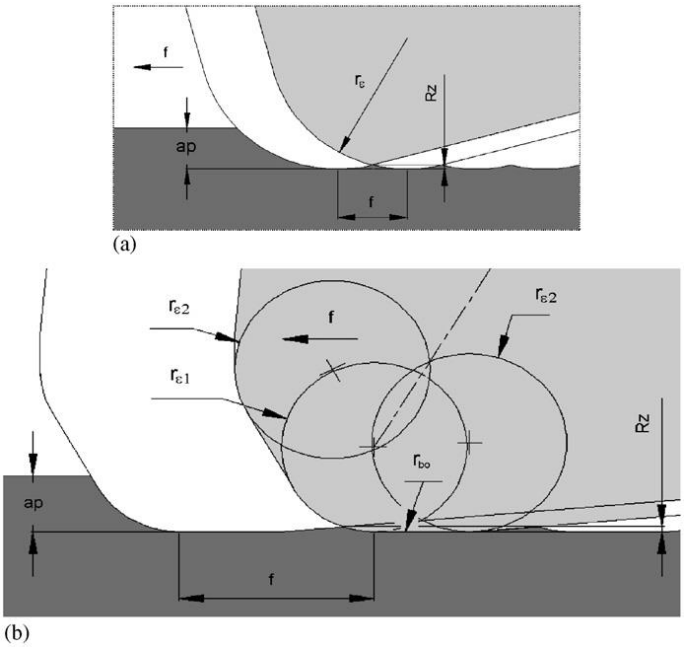


Fig 6: Comparison of inserts with conventional geometry (a) and wiper Shape (b). (Grzesik & Wanat) (2006)

Grzesik & Wanat (2006) in their investigation of Surface finish generated in hard turning of quenched alloy steel parts using conventional and wiper ceramic inserts reported that after turning with conventional inserts when varying feed rate in the range of f = 0.04–0.4 mm/rev the values of Ra parameter change from 0.24 to 5.47 mm, whereas corresponding values of Rz parameter (Fig.12a) range from 1.62 to 21.89 mm. The surfaces turned with Wiper inserts (when feed was selected at f = 0.1–0.8 mm/ rev) were characterized by the measured values of Ra parameter ranging from 0.28 to 6.03 mm, and Rz values between 1.54 and 23.3 mm (Fig.7a & 7b).

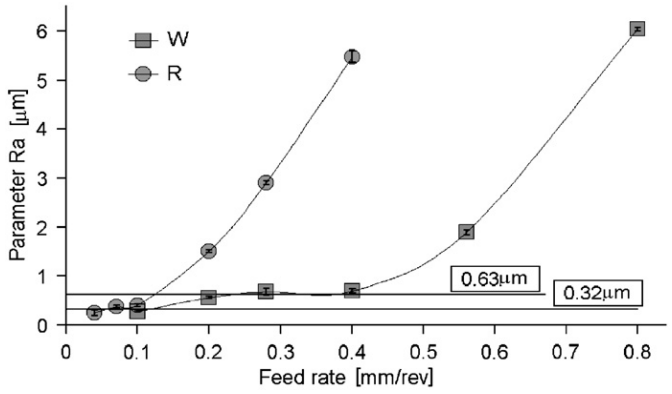


Fig 7a: Values of Ra parameter for turning with conventional (R) and wiper (W) tools. [Grzesik & Wanat(2006)]

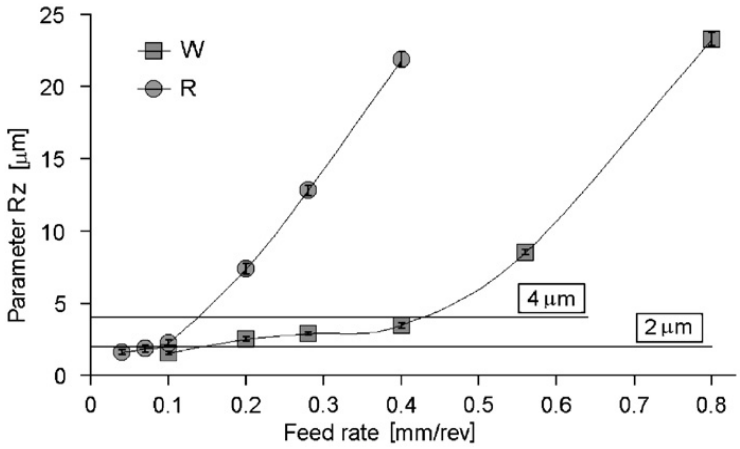


Fig. 7b: Values of Rz parameter for turning with conventional (R) and wiper (W) tools. [Grzesik & Wanat (2006)]

Also they reported that the RMS average wavelength (Rlq) decrease when applying lower feed rates. Their values change from RSm = 22.29 to 390 mm and from Rlq = 12.86 to 296 mm for

operations with the single radius inserts, and from RSm = 117.7 to 770 mm and from Rlq = 58.5 to 590.45 mm for wiper ones (Figs. 8a and 8b).

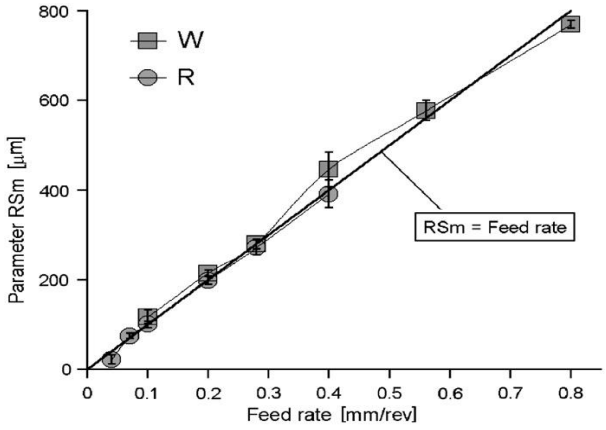


Fig 8a: Values of RSm parameter for turning with conventional (R) and wiper (W) tools. [Grzesik & Wanat (2006)]

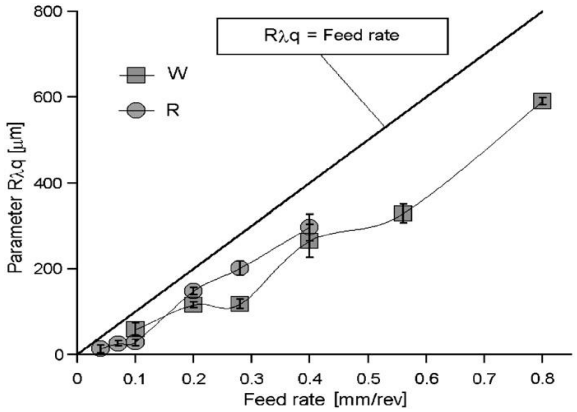


Fig. 8b: Values of Rlq parameter for turning with conventional (R) and wiper (W) tools. [Grzesik & Wanat (2006)]

Karpuschewski et al (2013) observed Influence of tool edge preparation on performance of ceramic tool inserts when hard turning. Tested ceramics, both uncoated and coated, have been thoroughly examined experimentally in order to identify the six quantities of edge preparation as coating thickness, friction force micro hardness, surface roughness of tool insert, tool edge rounding, tool edge sharpness. The measurement of quantities related to tool edge preparation by TiN coating represents the numerical data listed in (Table 2):

Table 2: Results of tool edge preparation

Type of Tool	Friction Force Fr(N)/10Kg	Hardness (Gpa)	Surface roughness of insert Ra(µm)	Coating thickness(µm)	Tool radius R_n (µm)	Tool edge sharpness Rt (µm)
Al2o3 +TiC mixed ceramics	94	2218	0.129	0	19.61	2.40
TiN coated Mixed Ceramics	68	21.66	0.083	1.98-2.03	19.42	1.38

Kishawy et al (2011) Modelling of tool wear during hard turning with self-propelled rotary tools the SEM images (Fig 9) of carbide tools after hard turning. One insert is fixed and the other one is allowed to rotate. It was observed that for a specific cutting condition the tool life has increased significantly when inserts are allowed to rotate. For tool life criteria of 0.3 mm and for speed of 130 m/min and feed of 0.1 mm/rev, the tool life increases from around 250 m cutting distance for the fixed tool to over 2600 m cutting distance for the rotating inserts. Catastrophic failure was the mode of tool wear for the fixed tool while flank wear was observed as the dominant mode of tool failure for the self-propelled one.

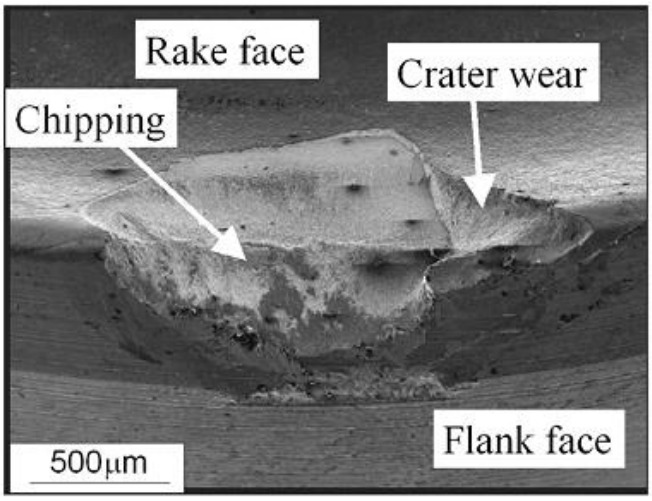


Fig: 9: Modes of tool wear during hard turning with rotary carbide tool. (a) Fixed tool (after few seconds) [Kishawy et al (2011)]

For the case of rotating insert there was no evidence of crater wear that is normally severe in hard turning due to the high temperature, especially with carbide tools (Fig 9). These images further proved the cooling efficiency of the rotary tool and therefore a longer tool life can be expected in comparison to a regular non-rotating insert.

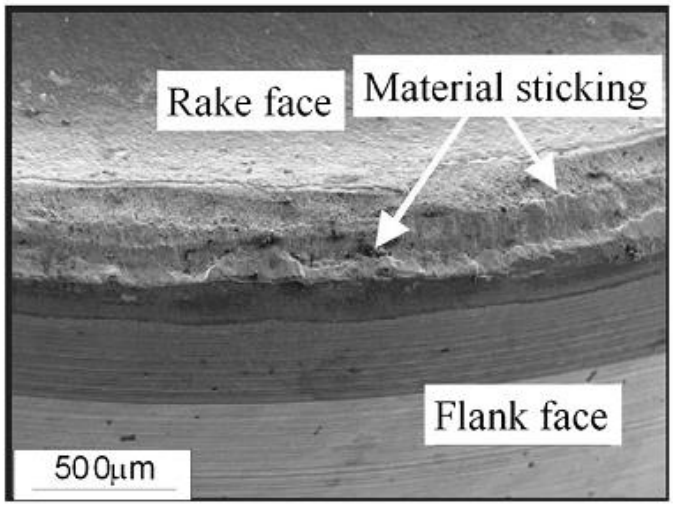


Fig 9: (b) Rotating tool (end of the tool life) [Kishawy et al (2011)]

During the cutting tests and tool wear model development, the feed rate was found to have similar impact as the cutting speed on the rotary tool flank wear progression in hard turning for the cutting speed range 139–446 m/min.

Aslantas et al. (2011) in their investigation on Tool life and wear mechanism of coated and uncoated Al2O3/TiCN mixed ceramic tools in turning hardened alloy steel reported that fracture and chipping type damages occur more frequently in uncoated tools, whereas crater wear is the more common type of damage in TiN coated tools. And TiN coating and crater wear affect chip flow direction. They further mentioned that in uncoated ceramic tool, the crater formation results in decrease of chip up-curl radius. Besides, uncoated cutting tool results in an increase in the temperature at the tool chip interface. This causes a thermal bi-metallic effect between the upper and lower sides of the chip that forces the chip to curl a smaller radius. Chips accumulate in front of the tool and stick to the work piece depending on the length of the cutting time.

El Hakim et al. (2011) illustrated the tribological complexity of the wear mechanisms of the different tool materials used in machining of medium hardened AISI T15 HSS. Investigated that CBN tools shows poor behavior with this HSS at higher cutting speeds. Chip compression ratio

was studied and at high speeds a decrease in the ratio with the Al2O3+TiC cutting tool was observed. The CCRs for chips produced from the coated carbide and the mixed alumina tools were found to be lower than that for the CBN tools. The lowest CCR values were found for high cutting speeds with the mixed alumina tool. SEM and EDS analysis of the worn surfaces on the cutting tools showed significant wear of the c-BN cutting tools due to abrasion from hard particles in the work piece. The coated carbide tool was worn due to progressive wear of the protective coating. The mixed ceramic tool was analyzed by Raman spectroscopy and the formation of different oxides was identified, notably iron oxides as well as some with aluminum and titanium. SEM mapping showed the presence of Al2O3 in the flank wear region.

Grzesik (2009) carried out experiment on wear development on wiper Al2O3–TiC mixed ceramic tools in hard machining of high strength steel. In finish MC HT, wear of tool flank faces is mainly concentrated on the tool corner and the active secondary cutting (trailing) edge in general, wear mechanisms in Al2O3–TiC ceramics sliding against the hardened low alloyed steel involve abrasion, fracture, plastic flow, adhesive tacking and material transfer and also tri-bochemical effects depending on the mechanical and thermal conditions generated in the machining tests. In the case of wiper ceramic tools two types of the transfer layer occur simultaneously on the rake face. The first (compact lump) is localized in a small area, whereas the second (scattered patch) with severe fragmentation and elongation is similar to the tail of a comet. As documented by appropriate energy-dispersive X-ray analysis, the smearing phenomenon of soft manganese sulphides was the onset of the generation of a stable built-up layer in the area adjacent to the chamfer. In addition, iron oxides are formed at high local temperatures on the sulphides. Examination of the ceramic tools used revealed that severe wear of the smoothing middle part of wiper corner along with rather uniform wear of the flank and rake faces was observed in this study. The material deposits on ridges and grooves have similar structure but different content of elements, mainly Al and Ti.

3. Need and Justification of Research

In manufacturing of automobile components like gears, axle, clutch plates etc. case hardening is done to improve mechanical properties such as hardness, strength and toughness. But after heat treatment process the steel components expand due to heating and cooling. These enlarged components need to reform in required dimensions. This is done by grinding process.

Hard turning is also an established process in industry for the finish machining of a wide range of range of hardened steel work pieces. In comparison to grinding, hard turning can offer significant advantages, namely that is far more flexible manufacturing method. Hard turning often used as a dry cutting process and have great ecological advantages. Some of the advantages of Hard turning over Grinding are,

- In hard turning, the machining becomes three times faster than grinding.
- As per an estimate, grinding cost is about four times the cost of hard turning. A CNC lathe is priced about half as much as a CNC grinder; and is also cheaper to maintain. Additionally, a CNC lathe is much more versatile and can complete machining of most of the surfaces in one set up without un-chucking. The same may require either more than one set up on a grinding machine, where each set up change over takes more time than on turning machine or more number of dedicated grinding machines. With no grinding sludge to handle, the process is more environment-friendly.
- Hard turning can today consistently maintain a size tolerance of +/- 0.010mm or better over long production runs and achieve surface finish less than 0.3 micron.

In spite of the obvious advantages hard turning is rarely used for manufacture of precision work pieces.

By analyzing the research papers, it was found that major work is done on the materials like cold work tool steel, AISI 52100, AISI 4140, AISI 4340 and very rare studies on 20MnCr5 grade steel. (S. Das)

The 20MnCr5 grade steel is widely used in the manufacturing of gears for automobiles and grinding is done after heat treatment (Information taken from Industry – Oerlikon Fairfield). If it is replaced by Hard turning, it can lead to improve the process output in terms of associated cost, cycle time and other aspects like environment and safety to the workers.

3.1 Objectives of Research

1. Study of current practices in Hard Turning of case hardening steels.
2. Analysis of effect of cutting parameters on surface finish and tool wear using ANOVA and Taguchi.
3. Multi-objective optimisation of cutting parameters for hard turning of case hardening steel using MCDM method.

3.2 Methodology

1. Review of literature to study existing work done in the area of Hard Turning of case hardening Steel.
2. Selection of tool material, tool geometry and cutting parameters – cutting speed, depth of cut and feed rate with respect to work material.
3. Formation of design of experiments using Taguchi Methodology.
4. Experimentation by varying cutting parameters.
5. Examination of cutting tool and work piece surface by appropriate measuring instrument like Surface Roughness Tester, Tool Maker's Microscope / Profile Projector and High Resolution Photography.
6. Analysis of results of experiments.
7. Multi objective optimisation of cutting parameters for hard turning process.
8. Interpretation of results.
9. Conclusion and documentation.

3.3 Comparison between Hard Turning & Grinding process

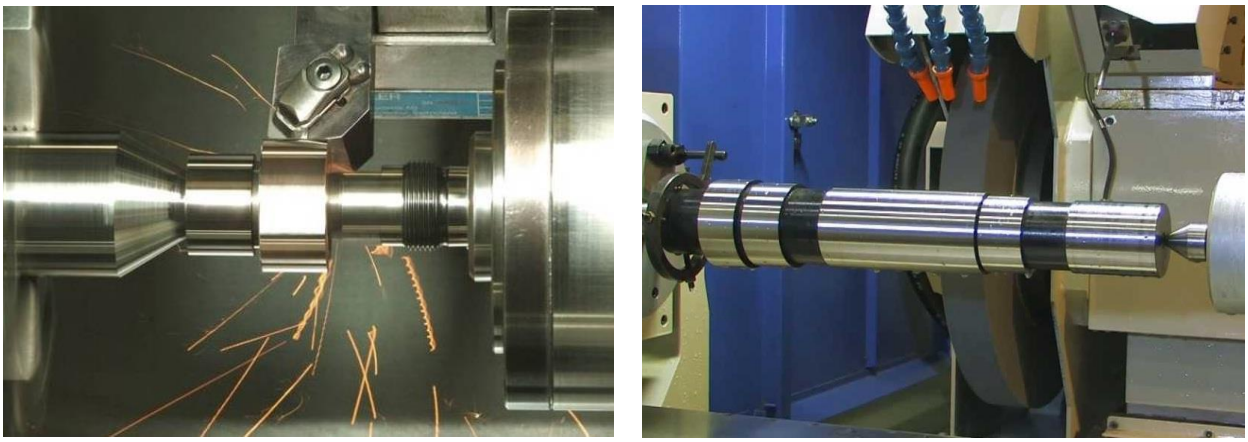


Fig. 10: Comparison between Hard Turning & cylindrical Grinding set up

4. Proposed work Plan/ Formulation and Structure of Study:

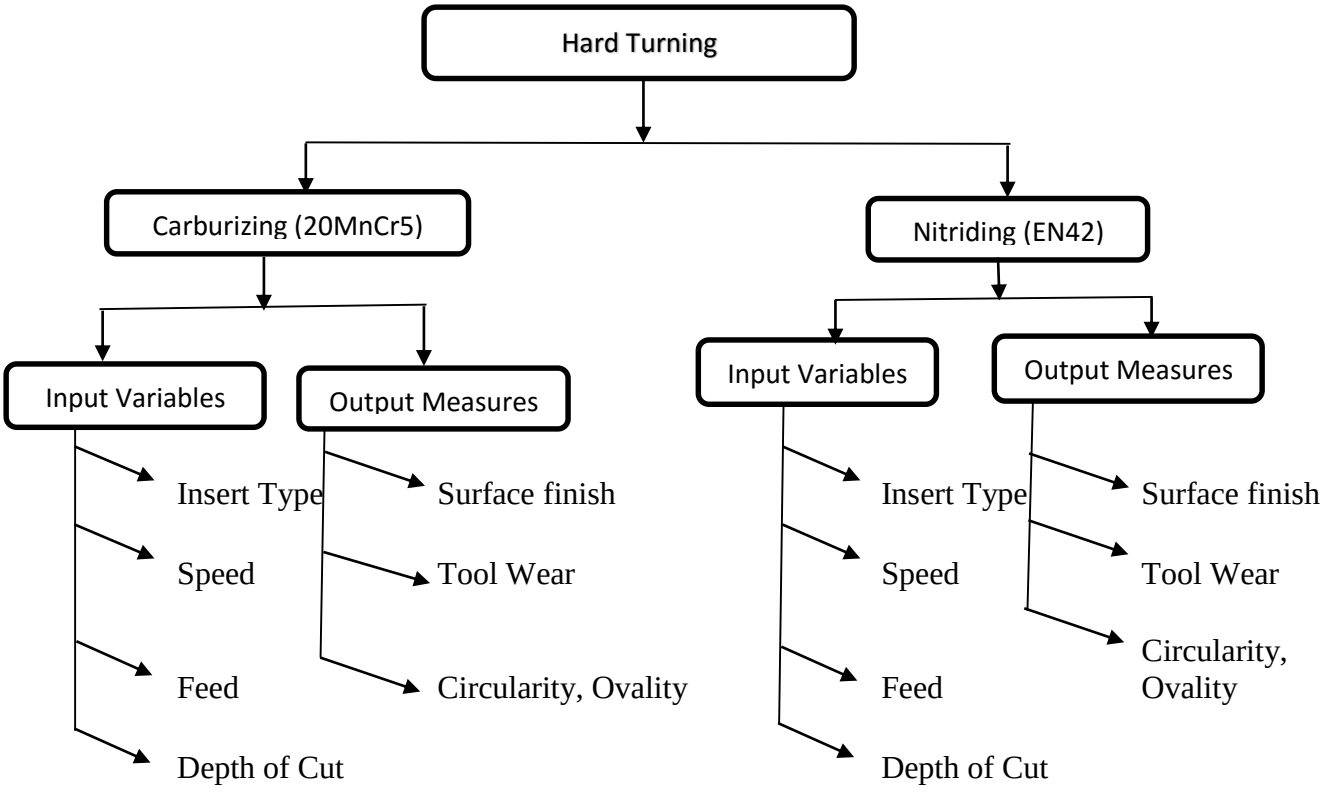


Fig. 11: Proposed Work Framework and Parameters.

4.1 Expected results from the Research:

Expected surface roughness of Steel after hard turning (Ra): 0.3 to 1.5 µM

5. References:

1. B. Karpuschewskia, K. Schmidta, J. Prilukovab, J. Benoc, I. Nkovac and N. Trong Hieud. (2013). "Influence of tool edge preparation on performance of ceramic tool inserts when hard turning." Journal of Materials Processing Technology, 213, 1978– 1988.
2. W. Grzesik (2009). "Wear development on wiper Al2O3–TiC mixed ceramic tools in hard machining of high strength steel" Wear, 266, 1021–1028
3. M.A. El Hakim, M. D. Abad, M. M. Abdelhameed, M. A. Shalaby and S. C. Veldhuis (2011). "Wear behavior of some cutting tool materials in hard turning of HSS" Tribology International, 44, 1174–1181.
4. H. A. Kishawy, LeiPang and M. Balazinski (2011). "Modeling of tool wear during hard turning with self-propelled rotary tools." International Journal of Mechanical Sciences, 53, 1015–1021.
5. J. Guddat, R. M' Saoubia, P. Alma and D. Meyerb (2011). "Hard turning of AISI 52100 using PCBN wiper geometry inserts and the resulting surface integrity". Procedia Engineering, 1st CIRP Conference on Surface Integrity, 19, 118 – 124
6. W. Grzesik and Z. Krzysztof (2012). "Modification of surface finish produced by hard turning using superfinishing and burnishing operations." Journal of Materials Processing Technology, 212, 315– 322.
7. R. Suresh, S. Basavarajappa and G. L. Samuel (2012). "Some studies on hard turning of AISI 4340 steel using multilayer coated carbide tool" Measurement, 45, 1872–1884.
8. N. Jouini, P. Revel, P.-E. Mazeran and M. Bigerelle (2013). "The ability of precision hard turning to increase rolling contact fatigue life." Tribology International, 59, 141–146.
9. Krishnaveni A., jebakani D., jeyakumar K., and pitchipoo, P. (2016) "Turning parameters optimization using copras – Taguchi technique" International journal of advanced engineering technology, 7, 463-468.
10. K. Aslantas, I. Ucun and A. Cicekc (2012) "Tool life and wear mechanism of coated and uncoated Al2O3/TiCN mixed ceramic tools in turning hardened alloy steel" Wear 274 – 275, 442– 451.
11. S. Das, D. Mohapatra, P. Routray and B. Rout (2015) "Effects and optimization of machining parameters in hard turning process: a review" Journal of Engineering Innovation and Research, 5, 1, 1 – 9.

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